68 Clinical Biomechanics of the Wrist

Melanie Amarasooriya, Simon MacLean, and Gregory I. Bain

Abbreviations

APL	Abductor pollicis longus
CMC	Carpometacarpal
D	Dorsal
DISI	Dorsal intercalated segmental instability
DRC	Dorsal radiocarpal ligament
DRUJ	Distal radioulnar joint
DTM	Dart thrower's motion
DTP	Dart thrower's plane
ECRB	Extensor carpi radialis brevis
ECRL	Extensor carpi radialis longus
ECU	Extensor carpi ulnaris
ECU	Extensor carpi ulnaris
EPL	Extensor pollicis longus
FCR	Flexor carpi radialis
FCU	Flexor carpi ulnaris
FPB	Flexor pollicis brevis
FPL	Flexor pollicis longus
FR	Flexor retinaculum
LC	Luno-capitate
LCHT	Luno-capito-hamate-triquetrum
LT	Luno-triquetral
PIN	Posterior interosseous nerve
RL	Radio-lunate
RLL	Radio-lunate ligament
RS	Radio-scaphoid
RSC	Radioscaphocapitate
RSL	Radioscapholunate
RUD	Radioulnar deviation
SC	Scapho-capitate
SL	Scapho-lunate
SLIL	Scapholunate instability
SLIL	Scapholunate interosseous ligament
STT	Scapho-trapezio-trapezoid
TC	Triquetro-capitate
TFCC	Triangular fibrocartilage complex
TH	Triquetro-hamate
Tq	Triquetrum
UC	Ulno-capitate
V	Volar
VISI	Volar intercalated segment instability

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68.1 Introduction

The wrist is a joint of remarkable mobility that enables the hand to function with precision, power and stability. Biomechanics of the wrist is the study of the physiological wrist motion (kinematics) and stability while bearing load without yielding (kinetics). In most texts, the two areas

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are separated, but in real life, it is the loaded wrist that moves. Therefore, in the study of wrist biomechanics, we believe, kinetics is equally important as kinematics.

In this chapter, we present how the wrist loads through the columns and mobilizes in the rows. The loading columns and moving rows are stabilized by multiple ligamentous rings, strategically positioned to create a universal joint that can stabilize the hand in any position in space, with or without grasping strength.

68.2 Carpal Kinetics

Carpal kinetics is the study of how carpus bears load without yielding. Carpus anatomically is divided into proximal and distal rows with extrinsic and intrinsic carpal ligaments stabilizing it. A number of theories such as row, column and oval ring theory attempt to describe bony anatomy with the mechanics of the wrist [1–4].

Under compression or traction, the carpal bones displace in a predictable way. They return to their normal position when the force is removed. The primary restraints for the carpus are the ligaments.

68.2.1 Columns, Rows and Rings

It had been debated over a century whether the wrist behaves as columns, rows or the oval ring. In a model where the loaded wrist is moving, maintaining its stability, it demonstrates features of all three concepts. The wrist is mobilized by the long wrist tendons and their muscles. The wrist loads axially in *columns*, moves as *rows* of functional units and is stabilized by ligamentous *rings*. Ligaments are supported by the dynamic action of muscles and neuromuscular feedback [5, 6]. In the following section, we discuss how each model contributes to its function.

68.2.1.1 Loading Columns

The force transmitted through the wrist is quite considerable. For example, a load applied to the tip of the finger generates loads as high as 1.2–4.6 times of that, on the corresponding CMC joint [7]. Nearly half of this is transmitted through the capitate, across the scaphoid and lunate [8]. Load distribution across the carpus is shown in Fig. 68.1. Wrist position affects this dynamics as radio-lunate (RL) articulation transfers more load on ulnar deviation [7]. In the functional position of the wrist, with slight extension and ulnar deviation, the radio-scaphoid (RS) joint transmits less load (40%) and RL more load (53%) [9] (Fig. 68.2). Each column is different with regard to the magnitude of the loads they transmit in each wrist position.

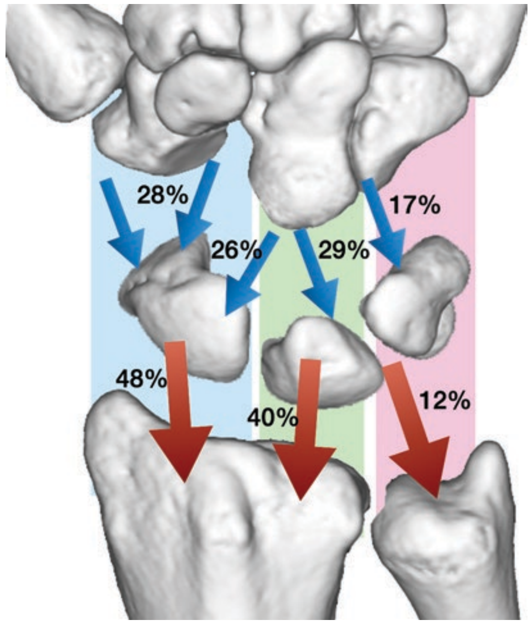

Fig. 68.1 The load distribution through the three columns. In the neutral position of the wrist, the radial column transmits more load than the ulnar and the central columns. Image copyright—Prof. Gregory I. Bain

68.2.1.2 The Rows

The wrist consists of the rows including the forearm, proximal carpal row and distal carpal row (Fig. 68.3).

68.2.1.3 Forearm Row

The forearm rotates around an axis from radial head to ulnar styloid. Thereby, the forearm sets the prono-supination angle for the wrist. Most of the wrist function occurs in relative forearm pronation.

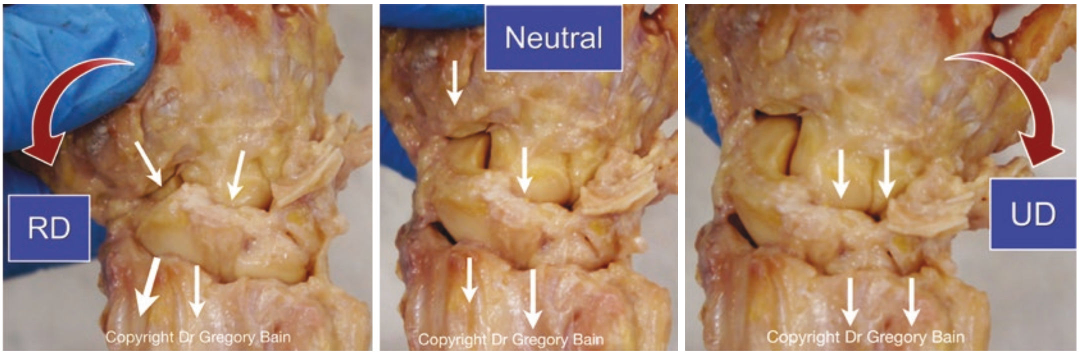

Fig. 68.2 The proximal carpal row swivels below the distal row and changes orientation with radio-ulnar deviation. The load distribution of the columns changes with wrist position. In radial deviation, the radio-scaphoid facet transmits more load. In ulnar deviation, the radio-lunate facet transmits more load

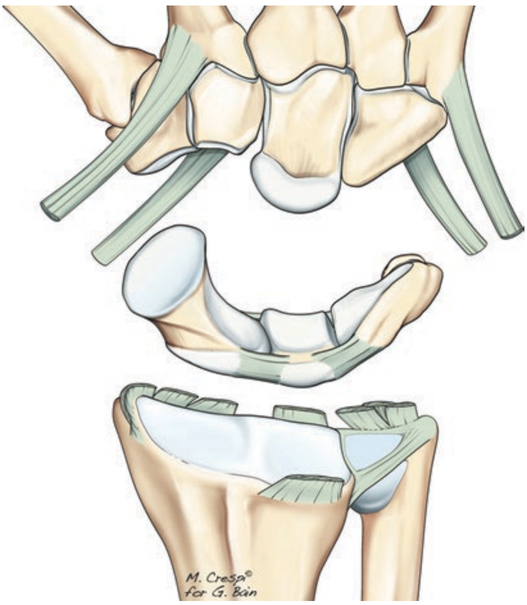

Fig. 68.3 This figure highlights the three carpal rows, the forearm, proximal and distal carpal rows. The bones in each row are tightly knit, stabilized by their own ligaments, creating a functional unit. Note how the wrist tendons insert into the metacarpals. (Copyright Gregory I. Bain and Max Crespi)

Radius

The radius has a steep inclination from radial to ulnar and dorsal to volar. This makes the radiocarpal joint intrinsically unstable. There are strong volar and dorsal extrinsic ligaments encircling the lunate and triquetrum preventing ulnar and volar translocation.

Ulna

While the radius makes the primary articulation with the carpus, the ulna remains the primary bone of the forearm. The entire wrist rotates around the foveal attachment of the TFCC. Thereby, the distal radioulnar joint (DRUJ) becomes an important load-bearing joint. The dorsal and volar radioulnar ligaments stabilize the DRUJ.

Proximal Carpal Row

The proximal carpal row consists of the scaphoid, lunate and triquetrum. It is named the 'intercalated segment' as no tendons attach to any of the bones. When the proximal carpal row is loaded, its motion is controlled by the distal carpal row and its bony contours and ligaments. Being positioned between the distal row and the forearm row, the proximal row swivels between them, depending upon the wrist position. Proximally, the greater arcuate ligament spans to the radius and ulna and bypasses the proximal carpal row. This allows the radius and ulna to swing beneath the capitate.

Lunate

The lunate has been referred to as the keystone of the carpus [10]. It is also the intercalated bone of the intercalated segment. It is tightly held onto the radius and other proximal carpal row bones by radio-lunate and interosseous ligaments, but there are no ligaments that extend from the lunate to the distal carpal row (Fig. 68.4).

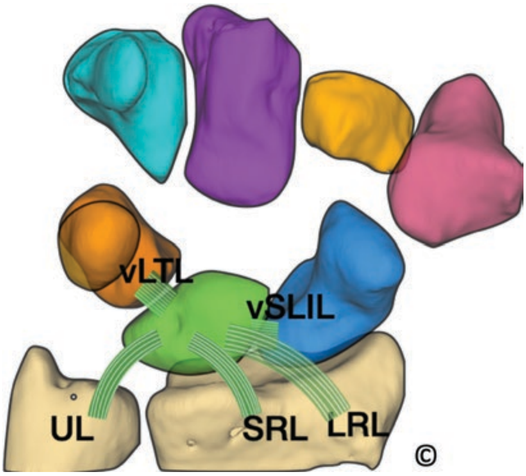

Fig. 68.4 The lunate and its ligaments. The lunate is tightly held to the radius and proximal row. No ligaments extend to the distal carpal row. Image copyrights—Dr. Melanie Amarasooriya and Prof. Gregory I. Bain

Scaphoid

The scaphoid is the 'trouble maker' of the wrist. It spans proximally from the scaphoid facet of the radius to the STT joint distally, spanning across the radiocarpal and the midcarpal joints. The long axis of the scaphoid is oblique, and scaphoid is positioned 'out of plane' to the central column, in a lateral view (Fig. 68.5). The scaphoid connects the radiocarpal joint and the STT joint which is located volar. The scaphoid functions like a 'gear lever' that is directed by the STT joint.

The scaphoid is restrained against volar translation by the radioscaphocapitate (RSC) ligament. It acts as 'seat belt' over which the scaphoid flexes (Fig. 68.6). The scapho-trapezio-trapezoid (STT) ligaments stabilize the distal pole of the scaphoid to the distal row. Dorsally the proximal scaphoid is restrained by the dorsal scapholunate interosseous (dSLIL) ligament, preventing dorsal subluxation of the proximal pole over the rim of the radius [11].

In a normal wrist, radial-sided angulation and radial extension forces are transmitted to the scaphoid through the STT joint. The scaphoid has no extrinsic ligamental attachment to the radius. The distal forces are transmitted to the proximal row via the attachments between the scaphoid and the proximal row, the scapholunate ligament. Thereby, it exerts a flexion moment on the lunate and guides the proximal row motion [12]. Thus, the scaphoid becomes the trouble maker and the gear lever of the wrist, while the scapholunate ligament is crucial to carpal stability.

Fig. 68.5 Lateral view of the wrist. Note the scaphoid is 'out of plane' to the remainder of the carpus and the thumb metacarpal. It spans from radiocarpal to STT joint, acting as a gear lever of the wrist

Triquetrum

The triquetrum is the sensory organ of the wrist [13]. It articulates with the hamate forming the flat biconcave triquetro-hamate joint (Fig. 68.7). During power grip, the flexor carpi ulnaris (FCU) pushes the pisiform and wedges the triquetrum onto the hamate.

Distal Carpal Row

The distal carpal row forms an arch, which is often considered a 'monoblock'. It is formed by the trapezium, trapezoid, capitate and hamate. It

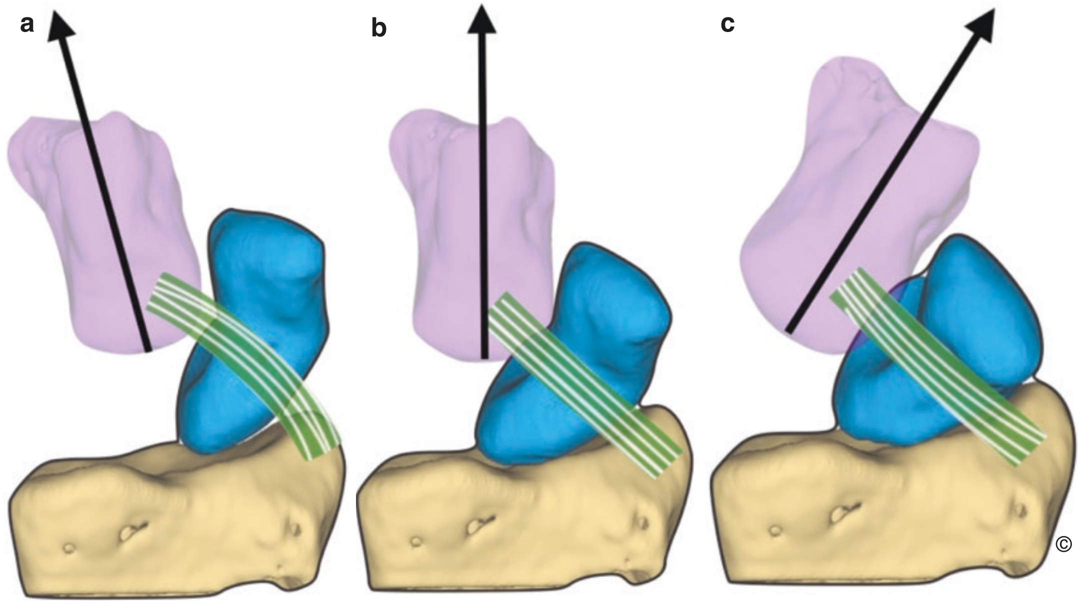

Fig. 68.6 The scaphoid flexes over the RSC ligament from ulnar to radial deviation. The distal row represented here with the capitate which deviates radially tensioning the RSC ligament. This prevents the volar translation of the scaphoid but allows the scaphoid to flex. It acts like a 'seat-belt' restraining volar translation but allows the scaphoid to flex over it, acting as a fulcrum at the waist. The scaphoid gradually flexes, allowing the capitate to move radially. (**a**) Ulnar deviation. (**b**) Neutral. (**c**) Radial deviation. Image copyrights—Dr. Melanie Amarasooriya and Prof. Gregory I. Bain

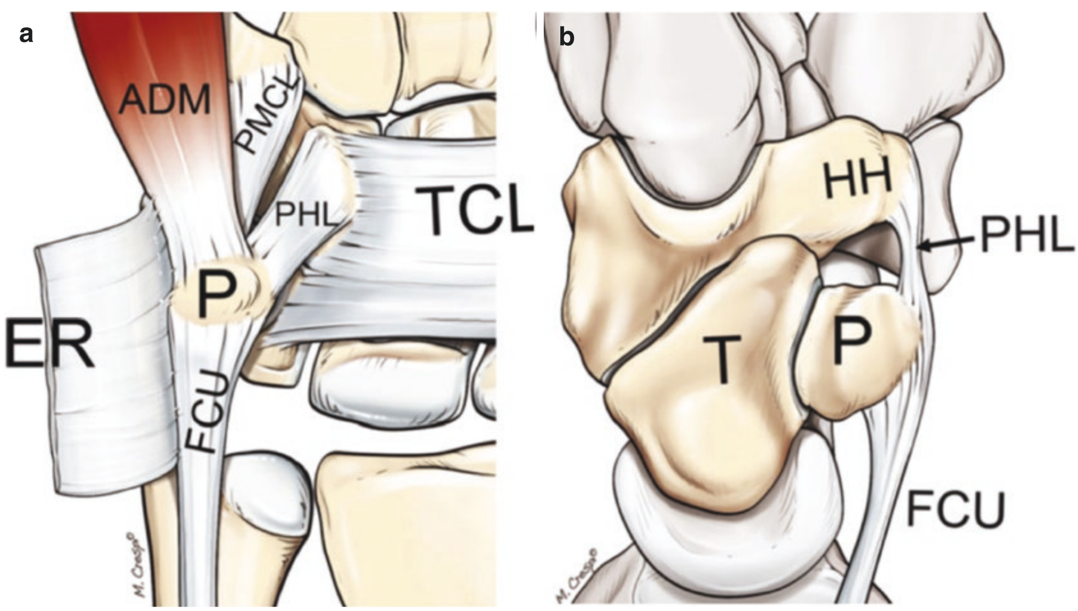

Fig. 68.7 FCU tendon and hypothenar muscles via their attachments to the pisiform mobilizes the ulnar column of the carpus. (**a**) FCU tendon and hypothenar muscle attachment to pisiform. (**b**) Triquetro-hamate joint is a flat biconcave joint. (Copyright Max Crespi. Reproduced from Compson J. (2012) Arthroscopic management of piso-triquetral conditions. In: Del Piñal F. (eds) Arthroscopic management of ulnar pain. Springer, Berlin, Heidelberg)

is stabilized by a ring of ligaments dorsally and volarly adding to transverse stability of the carpus.

The arch of the distal carpal row can be open and close. In quadrapods, this arch is important for loading during walking, as it absorbs the impact of the ground reaction force. When a person falls, this absorbs the load and transmits the force proximally. Thereby, depending on the age and the biology of the bony architecture of the person, ligamental injuries or distal radius fractures can occur. The concept of the monoblock is that during wrist motion the distal row works as a unit and swivels about the capitate. Volar to the arch is the transverse carpal ligament.

Capitate

The capitate has been underappreciated in carpal kinematics. If we reverse the layout of the wrist and place the capitate at the centre, we obtain a completely new appreciation of the importance of the capitate in wrist motion. There is a large proximal head that articulates with the proximal carpal row. The mechanical centre of the wrist is located within the proximal capitate. It is tightly bound to other distal carpal row bones with interosseous ligaments. There are no ligaments between the capitate and the lunate, restraining the luno-capitate motion. However, this ball and socket joint are stabilized indirectly from the periphery creating the universal joint (Fig. 68.8).

Trapezium and Trapazoid

Trapezium together with trapezoid forms the scaphotrapeziotrapezoid (STT) articulation. They are located volar to the plane of the capitate. The trapezoid is tightly held to the trapezium by the interosseous ligaments, so there is only minimal motion between them [14]. The trapezoid is more tightly held to the second metacarpal making it important for loading in grasp, while the trapezium is bound to the thumb, making it important for the pinch.

STT Joint

The STT joint is an interesting joint. It is a spherical flexion/extension ball and socket hinge joint.

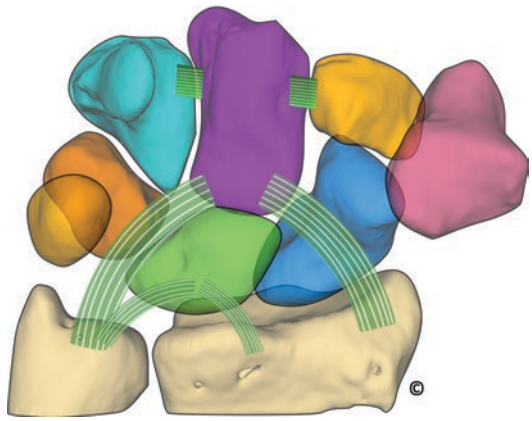

Fig. 68.8 Volar view of the wrist, demonstrating the greater and lesser arcuate ligaments stabilizing the capitate. The radio-scapho-capitate ligament, is the lateral limb of the arcuate ligament, spans from the radial styloid, to the volar radial surface of the capitate. It acts as a fulcrum around which the scaphoid flexes. The ulnar limb of the arcuate ligament is formed by the ulno capitate (UC) ligament, spanning from the fovea of the ulna and inserting to the volar ulnar capitate. This blends with the fibres of the radial limb to form the arcuate ligament. Proximal to the arcuate ligament is the space of 'poirier' through which the midcarpal joint dislocates in perilunate dislocations. Image copyrights—Dr. Melanie Amarasooriya and Dr. Gregory I. Bain

The capitate-trapezoid and trapezium complex (CTT complex) as a single unit 'rotates' around the distal scaphoid. When the scaphoid flexes, it is underappreciated that the STT joint hyperextends. This is important in clinical practice.

Trapezium and trapezoid produce scaphoid flexion and pronation with axial load. The distal row pronates around the luno-capitate axis [15, 16]. The hamate displaces dorsally exerting an extension moment on the triquetrum. Scapholunate (SL) and luno-triquetral (LT) ligaments balance the flexion and the extension forces on the lunate. Also, the lunate slides down the radial slope ulnarly.

Hamate

Hamate provides the attachment site for many important ligaments and takes an indirect attachment of the FCU tendon, through piso-hamate ligament, stabilizing the wrist for ulnar flexion. The ulnar deviation and flexion moments from the distal row get transferred to the proximal row

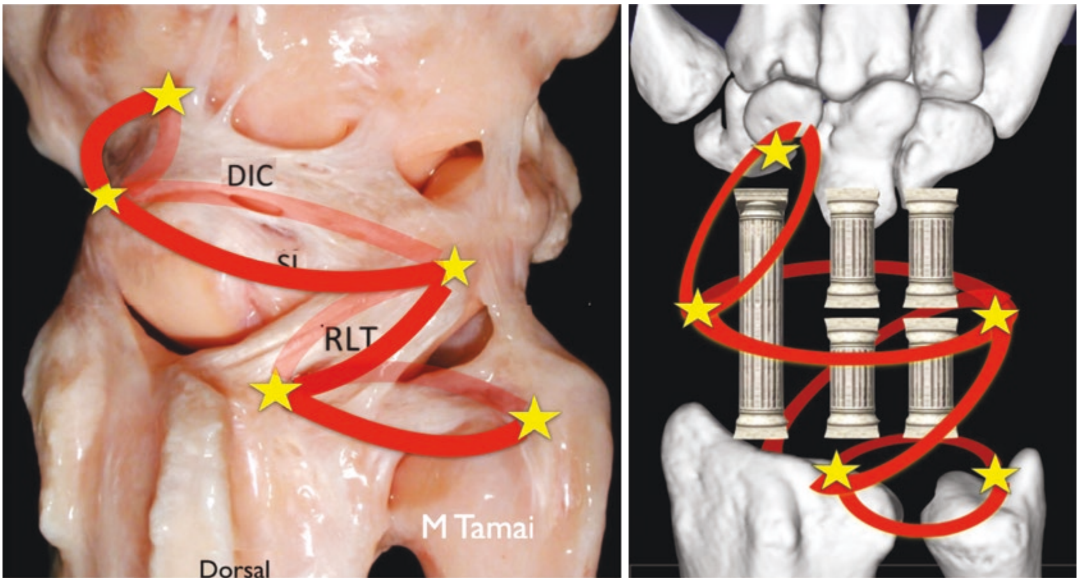

Fig. 68.9 Multiple ring theory; Carpus consists of three osseous rings. (1) Distal radioulnar joints stabilized by volar and dorsal radioulnar ligaments, (2) The proximal carpal row stabilized by dorsal intercarpal ligament and volar scapho triquetral ligament. (3) Distal carpal row stabilized by the volar and dorsal interosseous ligaments. The ligamentous rings that stabilize rows are indicated in red. (1) The radio triquetral ring (Kuhlman's sling) [25], dorsal radiocarpal ligament and the volar radio triquetral ligament. (2) The scaphoid-trapezium-trapezoid (STT) ring is a ball and socket hinge joint, consisting of the scapho trapezoid and scapho capitate ligaments. (3) The lesser arcuate ring consists of the ulnar lunate and radio lunate ligaments. (4) The greater arcuate ring consists of the radioscaphocapitate and the ulnar capitate ligaments, sites where the rings are linked, these form major stability points of the carpus and are indicated by stars (Nidus points)

via the hamate. The hook of the hamate and pisiform is volar to the remainder of the carpus, which increases the moment arm of flexion created by the FCU.

Pisiform

The pisiform is a sesamoid bone within the FCU tendon. Contraction of the FCU will pull the pisiform proximally, directing the hamate onto the triquetrum. Being a sesamoid bone, with an articular surface, it can move in a frictionless manner to enable it to guide over the triquetrum.

68.2.1.4 Ligamental Rings

The ligaments are often referred to as intrinsic (between carpal bones) and extrinsic (between carpal bones and radius or metacarpals) [17]. They are not arranged randomly throughout the carpus but form nidus points and are arranged into ligamentous ring complexes.

These rings are arranged as transversely stabilizing rows and helically interconnecting rows (Fig. 68.9). This is a mechanically advantageous construct for eight carpal bones that load as three columns while maintaining its mobility between the rows [18].

The radius has an inclination that involves ulnar and volar translation. Kuhlmann described a ligamentous ring (Kuhlmann's sling) from the radius to the triquetrum, including the dorsal radiocarpal ligament and the volar radio-luno-triquetral ligament (Fig. 68.10). This ligament prevents ulnar translocation of the carpus. Although the initial description is that it was to the triquetrum, our view is that it is the radiolunate ligament that prevents ulnar translocation. The lunate is tightly held by the dRLL and the vRLL.

Once the ligaments are damaged, instability develops. An example is scapholunate instability

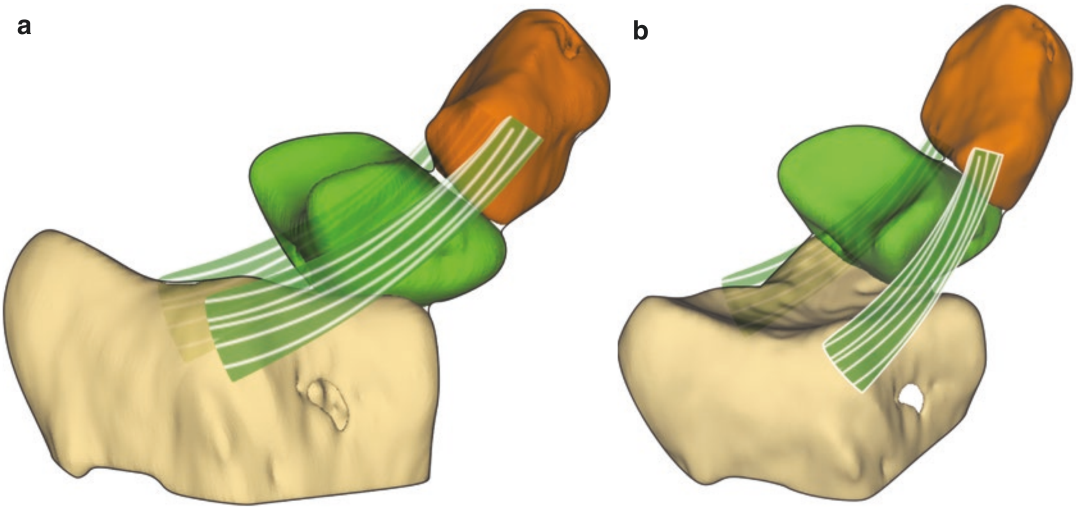

Fig. 68.10 Kuhlman's sling prevents ulnar translocation of the carpus. The Kuhlman's sling consists of volar radio triquetral ligament and dorsal radio luno triquetral ligament, also called the dorsal radiocarpal ligament (DRC). Being an obliquely arranged from distal radius to carpus, it acts as a sling, preventing ulnar translocation in the carpus. (**a**) Dorsal view. (**b**) Oblique view. Image copyrights—Dr. Melanie Amarasooriya and Dr. Gregory I. Bain

(SLI). In 'static' SLI, the lunate extends with the triquetrum while the scaphoid flexes and pronates with the distal row. This causes dorsal intercalated segmental instability (DISI) which is seen in static imaging such as X-ray and CT. When the lunotriquetral (LT) ligament is torn, the lunate flexes with the scaphoid, leading to Volar Intercalated Segmental Instability (VISI).

68.2.1.5 Tendons

The wrist flexors and extensors are strategically positioned to mobilize the wrist. But they also provide dynamic stability to the carpus. The tendons act as secondary stabilizers of the wrist. When ligaments are under strain, they transmit proprioceptive stimuli which recruit the muscles, which in turn unload the ligaments via the action of tendons [12].

68.2.1.6 Neuromuscular Coordination

The wrist capsule and ligaments are richly populated by proprioceptive nerve endings. Tension in a ligament activates them. The afferent stimuli travel through the branches of the posterior interosseous nerve (PIN) [5]. This, through a central neural mechanism, is transmitted to the muscles acting on the forearm. Within milliseconds, the protective muscles are positively recruited. These protective muscles will either prevent excessive supination or excessive pronation of the carpus, depending on the force to be counteracted. This will unload the ligament, reduce the diastasis and protect it [12].

This highlights the importance of the ligament and tendon attachments and the role of proprioception in rehabilitation of the wrist. In the same way, strengthening the 'friendly' muscles in rehabilitation may help in dynamic instabilities.

68.3 Carpal Kinematics

Carpal kinematics is the study of motion of the carpus in the physiological range. Anatomically, the wrist moves in two orthogonal planes, coronal and sagittal. In addition, there is carpal pronosupination relative to the radius. Carpal bones have six degrees of freedom to result in the said wrist motions. Each carpal bone can rotate around X, Y and Z axes and translate along these axes.

In real life, most of the human hand functions involve moving the wrist from radial extension to ulnar flexion, as in throwing a dart, casting a fishing rod or using a hammer. This motion is called the 'Dart Throwers' Motion' (DTM). The plane that the wrist moves during DTM is called 'Dart Throwers' plane' (DTP).

68.3.1 Dart Throwers Motion (DTM)

DTM occurs in a plane from radial extension to ulnar flexion. The axis of DTM is 26.6° ± 4.4° oblique to the sagittal plane and is believed to be the mechanical axis of the carpus [19]. DTM is the most stable and controlled motion of the wrist. It combines the power of the forearm muscles with precision provided by the thumb. Flexor carpi ulnaris (FCU) and the Extensor carpi radialis longus and brevis (ECRL and ECRB) become 'the wrist motor' for DTM. When radial extensors initiate DTM, the first joint to respond is STT joint with trapezium and trapezoid being pulled into radial extension, steering the dart throwers' motion.

DTM mainly occurs through the mid-carpal joint. It has two components. The first is STT joint acting as a uniaxial hinge, and the second is luno-capito-hamate-triquetrum (LCHT) joint acting as a biaxial joint. The two joints are connected by the scapho-capitate articulation and capitate-trapezoid articulations. Capitate-Trapezoid articulation has minimal motion. The scapho-capitate (midcarpal) articulation sits between the radial and the central columns and therefore is an important factor in determining motion between the radial and the central columns. The Scaphoid lies in a unique position connecting radiocarpal and mid-carpal joints.

The direction of scaphoid rotation in relation to radius is found to be the same irrespective of the direction of global wrist motion [20]. But the magnitude of the scaphoid rotation changes significantly between radioulnar deviation, DTM, flexion-extension and the planes in between. It is likely that multiple dart throwers' planes exist to suit functional tasks, with varying degrees of scaphoid and lunate rotations [21, 22].

The scaphoid is the 'Gear lever' of the carpus, and its motion is directed by its ligament attachment and adjacent articular surfaces. The scaphoid and the adjacent articulations will follow the paths of least resistance. Each joint will move as far as it can until its restraints restrict joint motion and force another component of the articulations to move. This explains the sequential motions of the articulations of the wrist and how the sequential restraints guide the inner workings of the various components of this amazing universal joint (Fig. 68.11).

Capitate together with the distal row, move in the desired plane, results in the global wrist motion. Scaphoid and the proximal row set the platform for the distal row to exert DTM in the desired plane. This occurs mainly at the SC articulation, with the scaphoid acting like a 'gear lever' making changes to the plane of the capitate and thereby the distal row. This can be explained by relative scapho-capitate kinematics.

In ulnar flexion, this reverses with mid-carpal joints moving to flexion, on the obliquely arranged proximal carpal platform. Midcarpal articulation is a C-shaped concavity. With ulnar flexion, the triquetrum rotates to complete the C so that it can smoothly accommodate the distal carpal row, mainly hamate, into ulnar flexion of the wrist [23]. The triquetrum-hamate articulation also stops the dorsoradial extreme movement of the distal row in DTM. The ulnar half of the arcuate ligament helps, with its fibres spanning from the distal rim of piso-triquetral articulation vertically onto the hamate and then obliquely onto capitate.

Hence, we believe that during functional wrist motion, the two *rows* act separately but with intricate coordination. The proximal row and distal row have specific functions. The proximal row changes the plane of the motion by changing the degree of scaphoid flexion and direction of lunate rotation. Distal row elicits the global wrist motion and is described by the capitate or the third metacarpal motion.

DTM occurs in pronation at the distal radioulnar joint (DRUJ) [24]. When the forearm is pronated, the line of action of the wrist extensors, as well as flexors, is oblique. Therefore, these muscles can effectively become radial extensors and ulnar flexors.

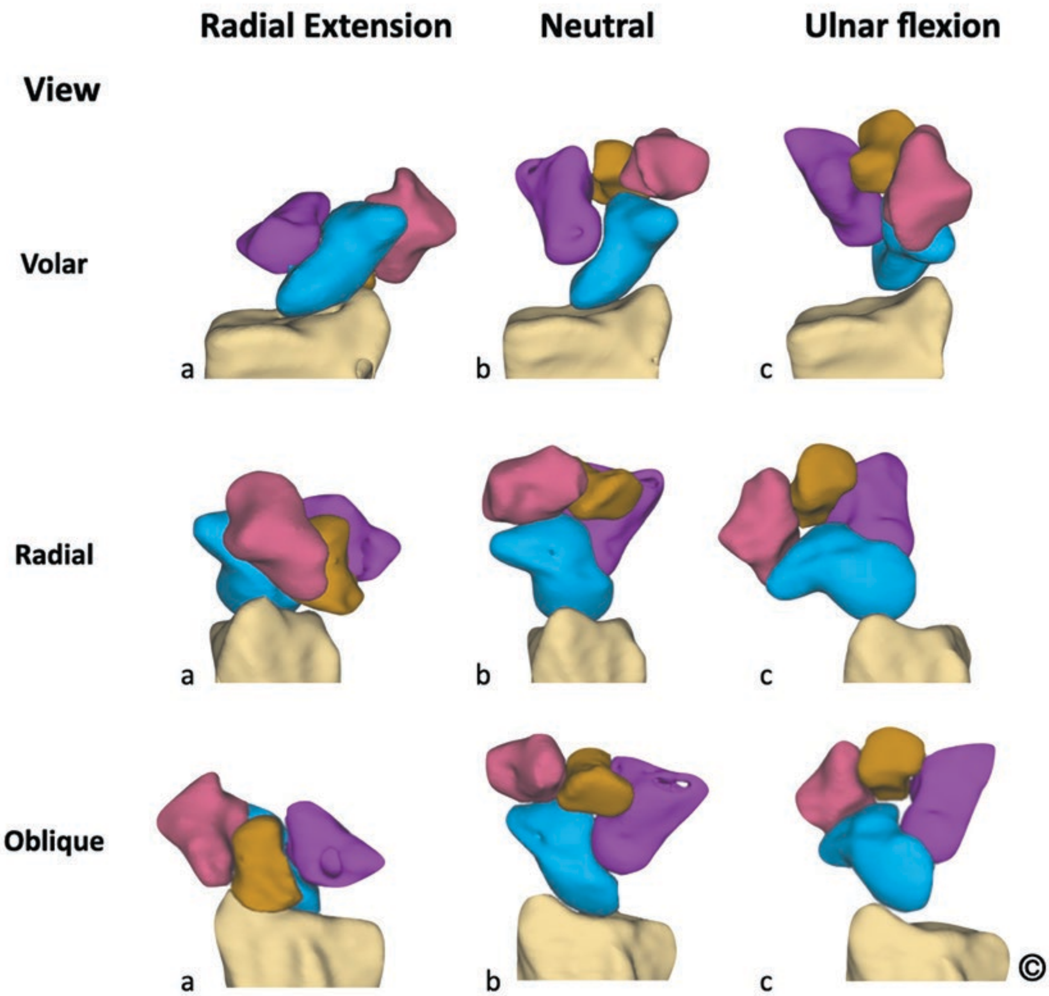

Fig. 68.11 Volar, radial and oblique views of the radial column during wrist dart thrower's motion. The capitate, trapezium and trapezoid moves from radial extension (**a**), neutral (**b**) to ulnar flexion (**c**). The scaphoid mainly shows an out-of-plane motion, from extension to flexion. Note in the oblique view, the dart throwers' plane lies in the axis of STT joint motion. The STT joint hyperextends, with radial extension of the wrist (oblique view a), then flexes as the wrist move into ulnar flexion (oblique view **c**)

68.3.2 Radioulnar Deviation

The radial deviators are ECRL, flexor carpi radialis (FCR), APL and EPL. The ulnar deviators are FCU and ECU. The radial pull of the tendons initiates a sequential motion pattern in the carpus. On a 2D coronal plane, this sequential motion appears as a rotation of the carpus, around the proximal pole of the capitate (Fig. 68.12). On a sagittal plane, the scaphoid flexion and trapezium moving over the dorsal surface are clearly seen (Fig. 68.13—oblique view). Even during radioulnar deviation, it is evident that the two *rows* move separately and the distal row positions determine the global wrist motion. The proximal row, with its out-of-plane motion, sets in the platform. This is orchestrated with sequential carpal motions as depicted in Fig. 68.12.

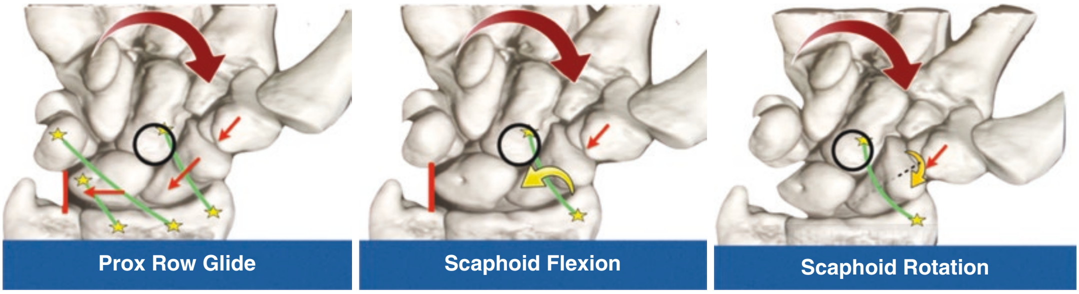

Fig. 68.12 Sequential motions of the proximal row during wrist radial deviation. Note the proximal row glide, followed by scaphoid flexion and then pronation

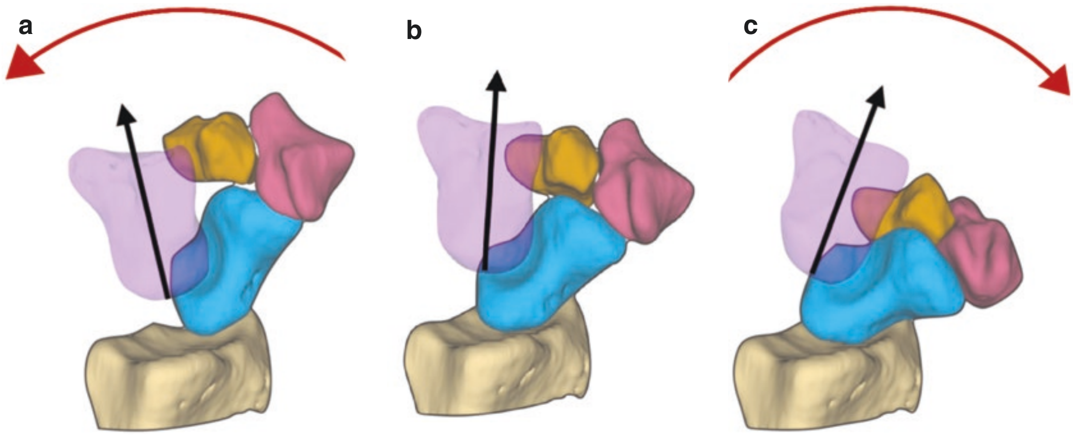

Fig. 68.13 Oblique view of the scapho-trapezio-trapezoid (STT) joint and capitate during ulnar to radial deviation of the wrist. Note that the STT joint is volar to the capitate. When the radial tendons pull the radial metacarpals and trapezium radially and proximally, capitate, being tightly bound to trapezoid moves with it, and the whole distal row follows. This is the direction of 'global wrist motion', radial deviation. However, because the STT joint is in a different plane to the capitate, that is volar, the STT joint has to hyperextend for the wrist (represented by capitate) to move radially. When the STT joint hyperextends, that occurs by trapezium sliding over the dorsum of the scaphoid and also scaphoid flexing. In radial deviation this 'out-of plane' rotation is very prominent to allow the distal row and capitate to angulate freely to radial side. (**a**) Ulnar deviation. (**b**) Neutral. (**c**) Radial deviation

68.3.3 Flexion and Extension

Flexion and extension are more congruent in terms of 'in-plane' motion. Flexor tendons and extensor tendons exert a flexion and extension moment, respectively, on the distal row first. Proximal intercalated segment dorsally translates and flexes as a response. Flexion-extension angles of each proximal row bone differ according to their proximal convexity. Due to this difference in flexion and extension of each bone, the SL and LT ligaments experience a rotatory torque. The transverse carpal ligament and the extensor retinaculum act as a 'pulley' preventing the bowstringing of the tendons.

68.3.4 Prono-supination

Prono-supination of the hand for functional activities occurs mainly at the forearm. However, carpus can also prono-supinate. Mean rotational laxity of the unloaded carpus is 42° [25]. Obliquity of the tendons enables the wrist to rotate around the Y-axis. It is an important observation that most of the functional tasks of the hand, including power grip, occur in relative DRUJ pronation.

68.3.5 Anatomic Variations Affecting Carpal Kinematics

Wrist is a joint that shows remarkable variations in anatomy between individuals. Carpal kinematics are known to vary between individuals due to anatomical variations.

68.3.5.1 Row and Column Type Wrists

Historically, there has been an interest whether the wrist behaves as two rows, proximal and distal or three columns, radial, central and ulnar. In the row-type wrist, the scaphoid translates more with radial deviation. In the column type, the scaphoid flexes more. The findings of later studies suggest that row and column type kinematics are a spectrum than a discrete entity [26].

68.3.5.2 Lunate Morphology

After Viegas (1990) described the presence of an extra facet of the lunate for hamate [27], Galley and Bain have proposed that this difference in scaphoid kinematics is due to the presence of type I and II lunates [28] (Fig. 68.14). The wrists with a type I lunate behave as a row type wrist and wrists with type 2 lunate as the column type. This is due to changes in mid-carpal kinematics.

The motion at the radiocarpal and mid-carpal joints will vary depending upon the lunate type [28]. In addition, this has a secondary effect on the loading of the carpus and subsequent arthritis.

68.3.5.3 Scaphoid Kinematics

There is similar variability observed with ligamental attachments of the scaphoid. The scaphoid can be of flexing and rotating types which can alter mid-carpal kinematics. The ligamentous anatomy of the scaphoid (Fig. 68.15) determines whether the scaphoid is a ‘flexing’ type or ‘rotating’ type [30].

68.4 Carpal Instability Patterns

Clinicians are familiar with diagnosing static carpal instabilities for years. Dynamic carpal instabilities pose a challenge as patients are often asymptomatic, and clinical examination may be equivocal. The clinical utility of dynamic imaging is invaluable in these circumstances [31].

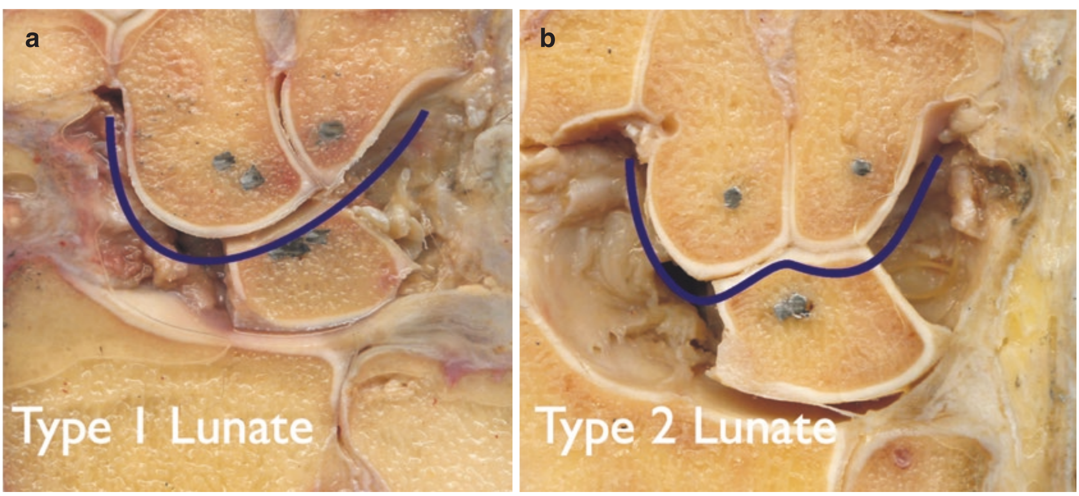

Fig. 68.14 The type 1 and 2 lunate articulations. (**a**) The type 1 lunate has a smooth midcarpal articulation, which behaves more like a hip joint, and does not restrain the midcarpal joint. As such scaphoid fractures, scapholunate instability and STT OA are more prone to develop a DISI deformity. (**b**) The type 2 lunate has two facets distally, which articulate with the capitate and the hamate. This restrains the degree of DISI deformity [29]

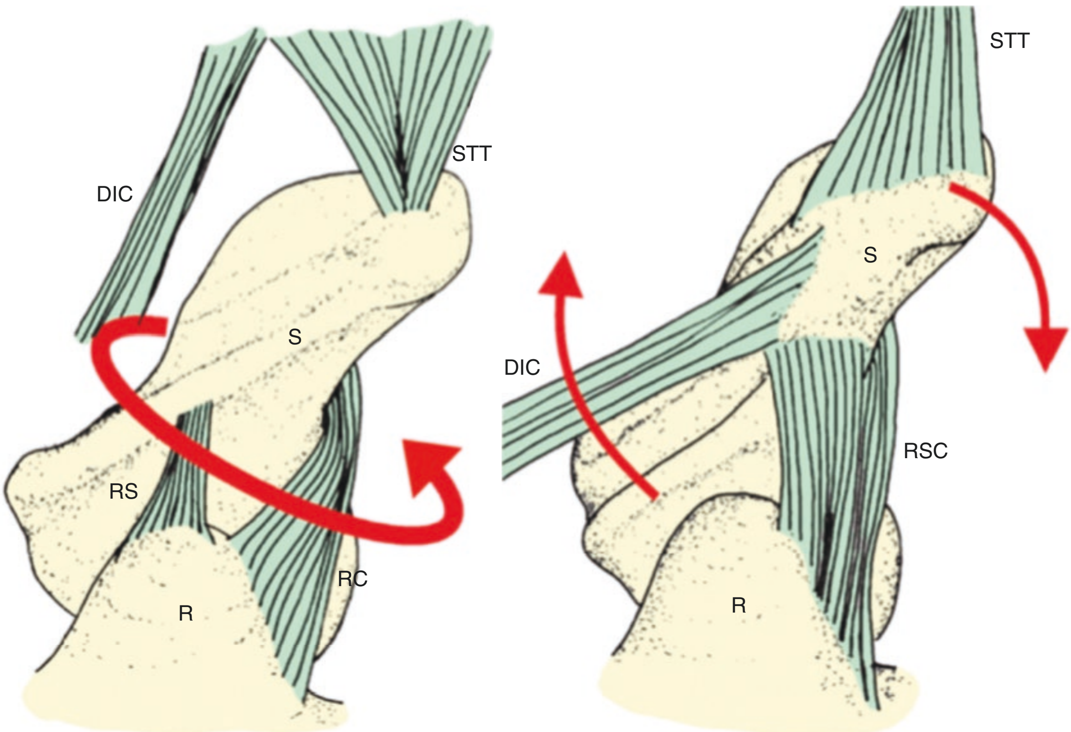

Fig. 68.15 There are anatomical variations of ligamental attachments to scaphoid, favouring rotation or flexion of the scaphoid [30]. From "Scaphoid variation and an anatomical basis for variable carpal mechanics," by Quintin Fogg, 2004, PhD Thesis, Adelaide University, p. 244 Copyright [2004] by Dr Quintin Fogg. Reprinted with permission from the author

68.4.1 Dynamic Computed Tomography (4D CT)

The 4D CT is a relatively low radiation dose tomography (0.3 mSv), where a sequence of 3D CT volumes is imaged by a helical scanner, as the patient moves the wrist. This is converted into a video graphic output. This enables to visualize carpal bone motion with natural wrist movements of the patient. The recent advancement of 4D CT is that the researchers are able to measure individual carpal bone motion and quantify patterns of instability.

68.4.2 Scapholunate Instability

The scaphoid in scapholunate instability, flexes, pronates and dorsally subluxes while translating radially during the wrist radial deviation. The lunate remains in its extended position. In addition to these well-known findings, 4D CT scans enable us to visualize and quantify the changes in scaphoid and lunate throughout the wrist range of motion (Figs. 68.16 and 68.17). This can be utilized to diagnose and classify dynamic instability as well.

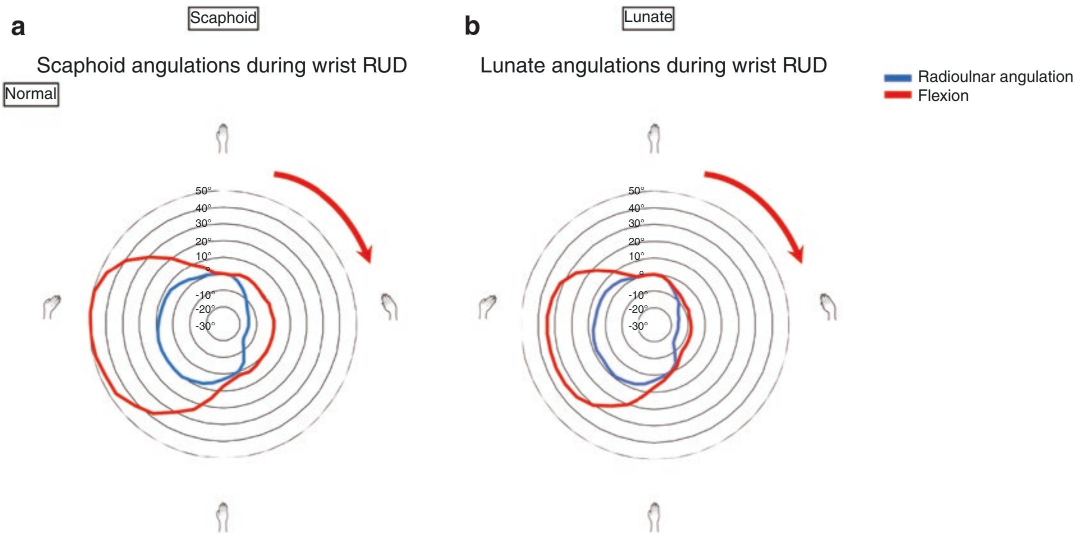

Fig. 68.16 The normal scaphoid and lunate angulations during the wrist radioulnar deviation. (**a**) Scaphoid angulations—The graph shows flexion of the scaphoid (red line) is more than the radioulnar angulation (blue line). (**b**) Lunate angulations—the graph shows flexion of the lunate (red line) is more than the radioulnar angulation (blue line) while the flexion of the lunate is less than the scaphoid, the graph patterns are similar and radioulnar angulation is similar in magnitude

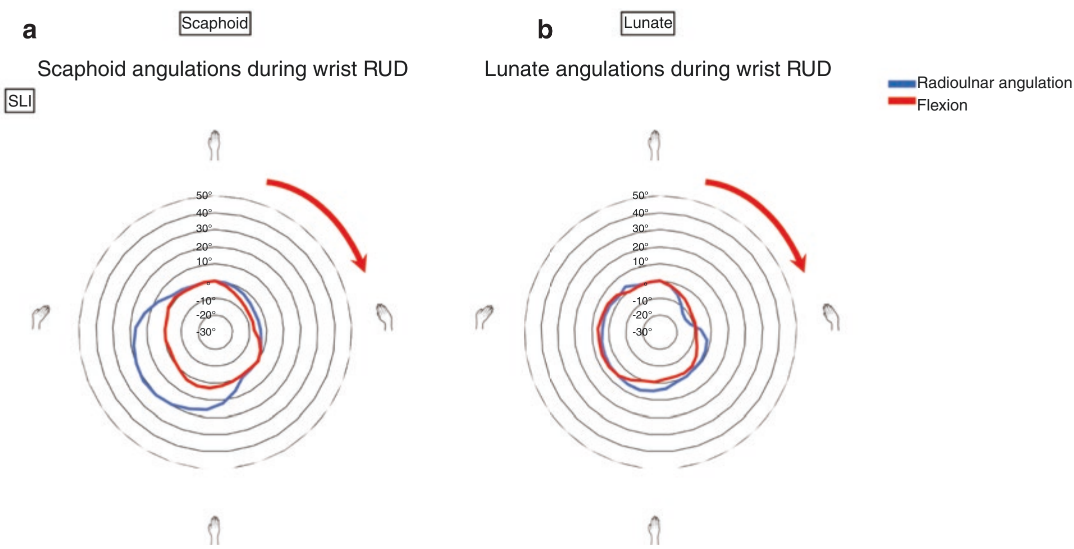

Fig. 68.17 The scaphoid and lunate angulations during the wrist radioulnar deviation in scapholunate instability. (**a**) Scaphoid angulations—the graph shows radioulnar angulation of the scaphoid (blue line) is more than the flexion (red line). This is reversal of the pattern seen in the normal wrist in figure F. (**b**) Lunate angulations—The graph shows flexion of the lunate (red line) is similar to the radioulnar angulation (Blue line). This pattern is different from the normal wrist

68.5 Summary

The loaded wrist shows remarkable stability due to ligaments, tendons and neuromuscular mechanisms. While the loading occurs via columns, the mobility of the wrist can be explained by rows. The multiple ligamental rings stabilize the wrist for loading and mobility. Dynamic CT imaging has been invaluable in our understanding of carpal biomechanics in vivo.

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